DEPLOYABLE SONAR SYSTEMS FOR UNDERWATER COMMUNICATIONS

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Abstract: This paper describes deployable underwater acoustic systems developed by Sensor Technology Limited. Two of these systems are based on a low-frequency barrel stave projector and a third one on a higher frequency transducer operating at 24kHz. The three systems are the Broadband Acoustic Transmission System (BATS), the Acoustic Communications System (ACOMS-D/P) and the Deployable Sonar System (DSS). The paper describes the transducers and the configuration and performance characteristics of the three systems based on them.

1. INTRODUCTION

The need for deployable underwater communication systems encompasses many applications including diver communications, communication pagers, active sonobuoys, marine mammal communication systems, acoustic counter measures, and portable research systems. These systems must provide reliable operation for both long (30NM) and short (5NM) ranges. All such systems require compactness and high efficiency in energy storage and operation. In addition, specialized functionality such as data encryption and equalization filtering for broadband response is often required. In this paper, three deployable underwater communication systems are described. Each system has its own unique functionality that is tailored to particular applications. The Broadband Acoustic Transmission System (BATS) transmits audible acoustic signals and is used in applications such as marine mammal research. The Acoustic Communications System (ACOMS-D/P) is a long-range communications pager with encryption capability. Both of these systems use a barrel-stave flextensional transducer. The Deployable Sonar System (DSS) is a portable sonar system that uses the Sensor Technology Limited SQ09 transducer operating at 24 kHz. The paper describes the system components, signal processing, system configurations, and performance.

2. SYSTEM COMPONENTS

The principal system components are shown in Fig. 1. In its simplest configuration, the system consists of six modules. A broadband transducer is used in most applications, but other transducers have been used in special applications. The transducer is described in detail in Section 3. A matching network ensures the efficient delivery of power from the power amplifier to the transducer. In these systems, the matching networks have been carefully designed based on the equivalent circuit analysis of a loaded transducer. The matching network also provides some amplification of the generated signals to improve the acoustic output. Typically the matching network consisted of a transformer and/or an inductor. These components were fabricated from saturated iron core materials.

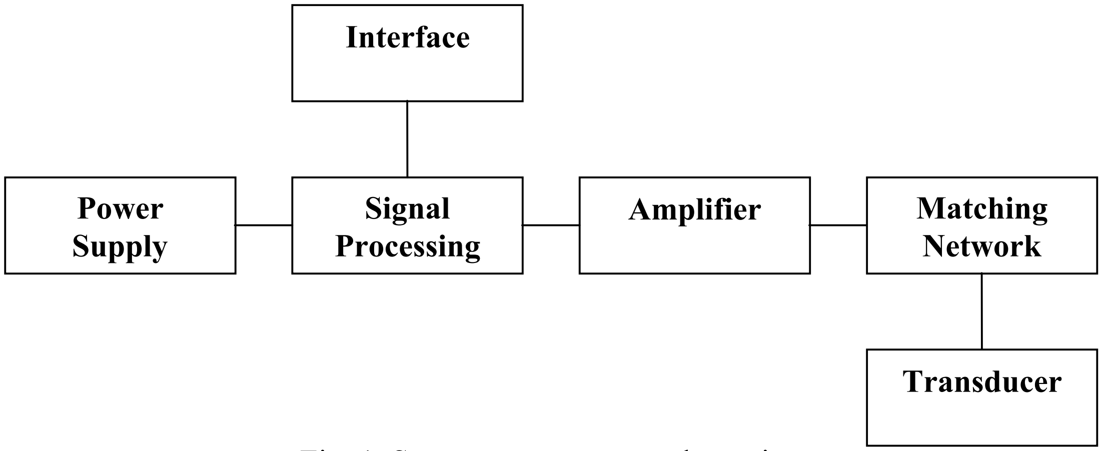


Fig. 1. System components schematic

The amplifier used in these systems is based on a MOSFET design and has a bandwidth of over 120 kHz with carefully trimmed components. Most applications require a bandwidth of less than 30 kHz. Piezoelectric materials used in the transducer fabrication produce dangerous reverse voltage spikes and unless care is taken in the design, these spikes would destroy the output transistors. In the design of these amplifiers, feedback circuits have been used to prevent electrical breakdown due to negative voltage spikes. The amplifier was configured as a standard 300-watt unit with floating outputs. If additional power is required, two amplifiers were connected in a bridge mode configuration to deliver a total of 600 watts of electrical power. Typically, the input of the amplifier is limited to 1V of input signal and will accept input signals from a variety of sources such as digital signal processors (DSPs), tape and CD players, and waveform generators. The signal-processing module is described in detail in Section 4. An interface module permits the transferring of waveforms and data from external sources.

Power supply is a critical component of these systems. The actual power supply used is generally a compromise of operational life, cost, and weight. A disposable battery pack gives the system fully deployable capability. An external battery will facilitate repeat experimental investigations economical. The system configurations typically require a small boat in such circumstances. Generally a voltage inverter is used to step up the voltage from a battery pack. It is necessary that the inverter frequency be carefully chosen not to interfere with the operations as well as to use filters to remove any residual ripple. These modules are normally packaged with careful grounding and shielding. In the ACOMS-D/P system, several shield plates were used reduce interference between various modules. In addition, the output transistors of the amplifier need a good heat sink for reliable and trouble-free operation.

3. TRANSDUCERS

The barrel-stave flextensional transducer consists of a piezoelectric stack forced into an extension-compression vibration by an applied electric field, and a shell excited at its first flextensional mode. The piezoelectric stack is held in tension by a central stress rod, and the concave curvature increases this pre-stress with hydrostatic pressure. A neoprene boot provides the necessary seal against water.

The transducers used in two of these three devices are barrel stave designs that fall into the Class I and Class III designations of flextensional transducer in the Brigham-Royster classification scheme [1,2]. A Class III design is basically an end-to-end graft of two Class I transducers. This dual-shell design is capable of broadband radiation due to multimode coupling between the fundamental flexural resonance of the staves and the longitudinal resonance of the driver. The transducers are patented in the US and Canada [3] and are produced in two sizes. The SX100-1 is a compact version of the SX100-2 that operates at 1.5kHz resonant frequency with a 500Hz bandwidth (-3dB). The larger version has a resonance frequency of 1.3kHz. Figure 2 shows a cutaway view of the SX100-1 and also its TVR curve.

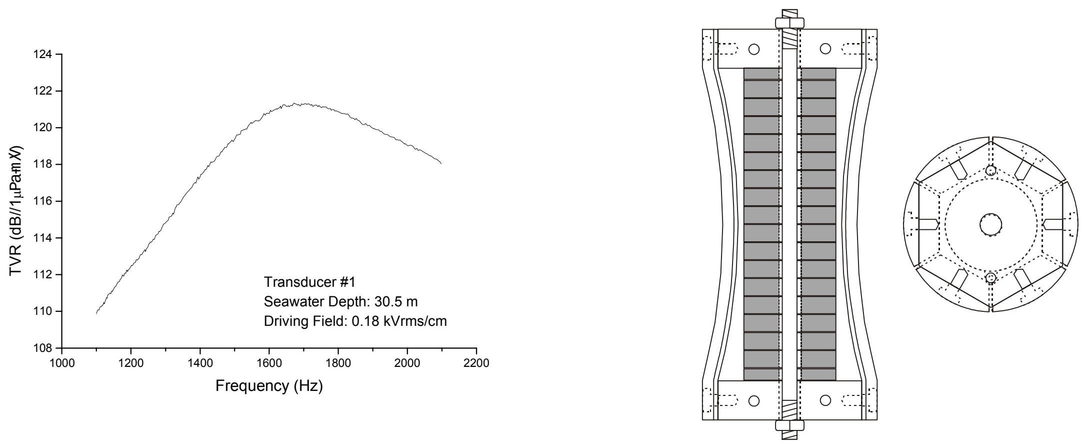


Fig. 2. Cutaway view of SX100-1 transducer and its TVR curve

For the SX100-1, the maximum outside diameter, overall length, and mass of the transducer are 5.9cm, 12.7cm, and 1.1kg, respectively. Measurements on the transducer show a resonance frequency of 1.6kHz and a transmit voltage response (TVR) of 125dB re 1μPa.m/V. Sound pressure levels (SPL) of 200dB re 1μPa have been achieved at driving fields of 4.5 kVrms/cm and a depth of 75m. The SX100-2 has a maximum outside diameter of 85mm, a length of 280mm and a weight of 3.9kg.

The transducer used in the third device described in this report is a general-purpose projector and hydrophone (SQ09). It has good sensitivity and depth capability. The transducer properties are stable with both temperature and depth. Its voltage sensitivity is 25V/bar and, unlike the SX100 transducers, it can operate to 2500m depth. As a projector, it can be driven with signals of up to 1000Vrms and its response is flat up to 24kHz. It has an outside diameter of 50mm and a length of 65mm.

4. SIGNAL PROCESSING

Several capabilities have been built into the design of the deployable sonar system. In its basic form, the system accepts signals from an external source, such as a waveform synthesizer or a tape or disc player. For more sophisticated applications, the system is configured with the following features.

Signal Generation

On board DSPs can generate simple or encrypted messages. The ACOMS-D/P used an 8-bit processor and waveforms in PCM format employing 4096 points per message were used. This is just a typical configuration; 16-bit processors and other file formats can also be used with these systems. The processor also performs the filtering and averaging.

Inverse TVR (iTVR) filter

The iTVR filter is a key component of the deployable system. It is generally difficult to build very high-power broadband transducers. The iTVR filter helps in smoothing out any residual non-linearity in the transducer transmit voltage response (TVR). Its performance is very similar to that of an equalizer. A large number of channels provide a greater control on the output of the system.

Signal Interface

The signal interface permits interfacing the system with other devices. This can be accomplished through the implementation of most common configurations such as RS232, RS485, GPIB, or USB. Another useful interface that permits non-contact operation is an infrared interface. In the deployable pager, a large number of messages were stored in a computer and were downloaded into the signal processor for trials. The type of message structure used depended on the surrounding conditions in the sea trial. Another useful implementation of this concept is to pre-load the messages into a personal information manager PIM and then arm the system with the desired message from the PIM.

5. OPERATIONS SUPPORT

Application of Portable Systems

Deployables can be used in a number of applications that include commercial, military, and scientific work. These systems can be used as either ship or boat deployed hardware or airdropped buoys. The signal-processing module allows a wide variety of applications by various end users. Other applications not described here include portable research systems and systems for acoustic countermeasures.

Diver Communications

The deployment and recovery of divers is important in both commercial and military operations. However communications between the various units involved (ship, launch vehicles, and divers) are greatly restricted. Therefore, most operations are largely undertaken according to a pre-arranged plan and timetable. Clearly this presents less than optimal flexibility and exposes such operations to increased risk should the situation change.

The deployable systems described in this paper are unique in that they use a low frequency (<2 kHz) communications system that can be engineered into a small compact handheld unit. Such systems are highly doppler-tolerant, have a long range for a given source power, and provide an integrated route to communications.

Communication Pagers

The architecture of a communications pager is similar to the diver communications system, with the exception that much higher power levels are used to achieve longer ranges (up to 80NM). The communications pagers employ a technique commonly known as constrained data signalling. In this technique the actual transmissions to be sent are restricted to some predefined group of physical transmissions. Information is mapped onto this physical transmission set by a message database held on board the transmitter and receiver. This technique facilitates efficient signal design and provides one-time pad encryption of messages. The receiver is programmed to identify all possible transmission sequences and enable a correlative detection algorithm to extract the information.

Active Sonobuoys

Active sonobuoys are designed to detect low-noise submarines at great distance. Active sonobuoys can be used together with passive sonobuoys, for threat localization or as the active projector of a multi-static operation where other sonars such as dipping sonars or surface vessel sonars are used as the passive receptors. The SX100 transducers have been redesigned to deliver source levels of up to 200 dB for such active sonobuoys.

Marine Mammal Communications

The broadband capability of these portable systems makes them an ideal tool for communications with marine mammals. They can be positioned in the required areas in small craft and the mammals are not threatened with the presence of large vessels. BATS system has been used successfully to communicate with pilot whales off the coast of Cape Breton in Canada [4].

6. TYPICAL SYSTEM CONFIGURATIONS

BATS

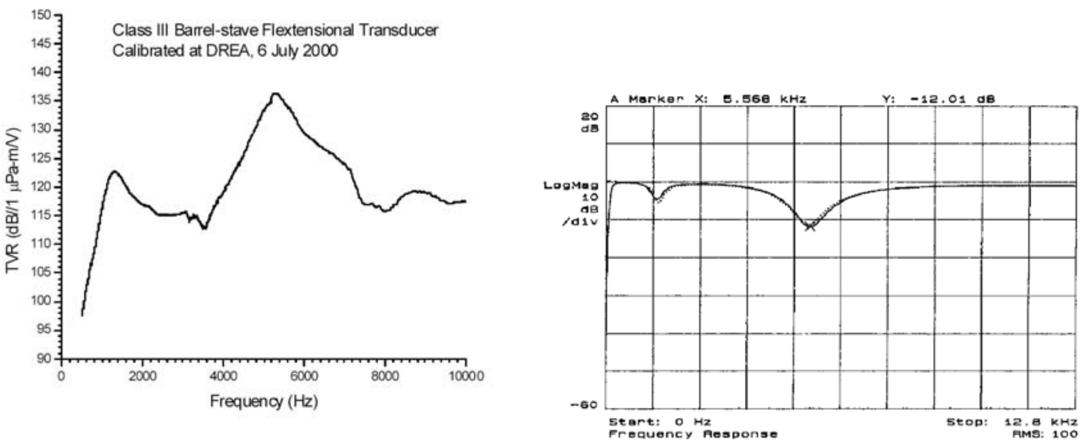
BATS (Broadband Acoustic Transmission System) is a portable system that can be deployed by one person from nearly any floating platform and is designed to be powered by a 12-Volt marine battery. It uses a Class I or Class III barrel stave flextensional transducer to transmit broadband acoustic signals into the water for experimental work at sea and finds use in a number of naval, commercial, and scientific research applications. For the Class III transducer, mechanical coupling between two collinear cylindrical shells gives rise to a fundamental flexural resonance at 1300Hz, a longitudinal resonance at 5500Hz, and higher order flexural modes above 8000Hz. These modes combine to allow this transducer to produce useful acoustic output throughout the entire 1kHz-14kHz frequency band. Figure 3 shows a typical package configuration for BATS with a Class III transducer.

Fig. 3. Typical configuration of a Broadband Acoustic Transmission

The BATS amplifier and the controls are housed in a compact control console. The system accepts signals from a wide variety of sources that include audio components such as cassette and minidisk

Fig. 4. TVR of an SX100-2 and the compensating iTVR curve

players, CD players, PC sound cards, and signal synthesizers. Adjusting the input signal to the amplifier controls acoustic output, and the signal is coupled to the transducer through an output transformer. A filter at the input of the amplifier facilitates the emulation of the inverse TVR profiles of the flextensional transducer and permits limited control over the flatness of the transducer response. An optional 31-band 1/3-octave equalizer will provide improved control of the output of the system. Thus, BATS is no more complicated to operate than any common audio device. Figure 4 shows the TVR of the SX100-2 transducer and the iTVR output of the equalizer.



A cable and reel connect the transducer to the control box. The BATS system provides a 1-14 kHz operating frequency band. The BATS source level at any given frequency in the band is limited to about 165 dB//1µPa-m.

ACOMS-D/P

The system known as ACOMS-D/P (Acoustic Communications System-Deployable Pager) was developed in 2000-2001 in response to a requirement from the Canadian Department of National Defence. It is designed as a disposable sonobuoy that can be used to broadcast information over a wide

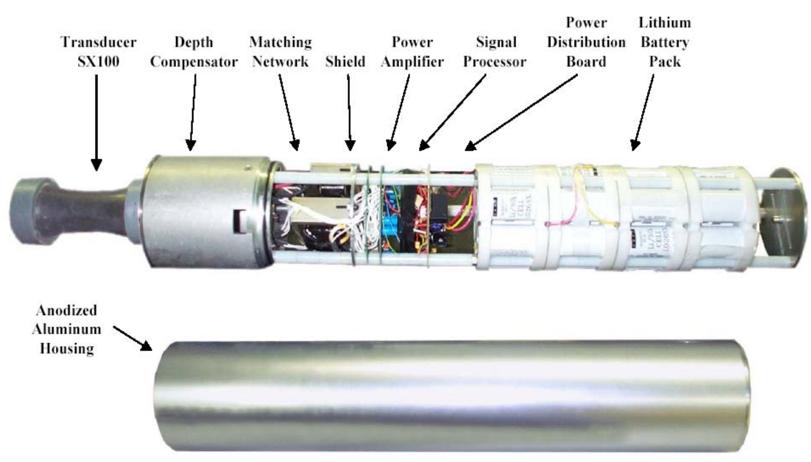


Fig. 5. SS04 ACOMS-D/P deployable communications

area underwater. The unit comprises a battery pack, signal processor, power amplifier, and an SX100-1 transducer with matching network. With a resonant frequency of 1500Hz, a Q of three, and capable of producing source levels up to 184dB re 1µPa, the ACOMS-D/P can broadcast information encoded into an audible carrier wave 30 nautical miles. Figure 5 shows the configuration of the ACOMS-D/P. The unit shown is fitted with a passive pressure compensation system that increases the depth to which the pager can work.

DSS

The DSS Deployable Sonar System is a powerful sonar source that runs on an external 12-Volt battery and is easily transportable and deployable. The transducer described here is a SensorTech SQ09 that is omnidirectional up to 24kHz and is driven by a 150watt (RMS) MOSFET amplifier through a matching transformer for optimal efficiency. The transducer is protected from damage by a reinforced cage fitted to the end of the watertight housing. It should be noted that an SX100 can be used with this configuration when a low-frequency broadband signal is desired.

Signals are sent to the amplifier from an external source and transmitted into the water through the SQ09 transducer. The DSS is suitable for use in small bodies of water and other situations where portability and power are prime considerations.

Figure 6 shows the DSS with its casing on and a view of the amplifier and matching transformer. The SQ09 is shown inside its protective cage.

Fig. 6. DSS deployable sonar system

7. CONCLUSIONS

Three deployable acoustic communication systems with unique functionality and characteristics have been described. Each system has a compact design and can be operated under battery power from a small vessel. The system modularity allows rapid customization for a broad range of applications in underwater communications.

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